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VERIFICATION OF THE PRESENCE OF WEAPONS-QUALITY PLUTONIUM IN SEALED STORAGE CONTAINERS FOR THE TRILATERAL INITIATIVE DEMONSTRATION*

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DISCLAIMER

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Abstract

In 1999 under the aegis of the Trilateral Initiative, a demonstration of a prototype Inspection System with Information Barrier (ISIB) for the determination of attributes of plutonium in sealed storage containers was made to a delegation from the Russian Federation [1,2]. The primary purpose of this demonstration was to show the feasibility of using an "information barrier" that protects sensitive information yet yields results that are useful to the monitoring party and can be accepted with high confidence as genuine. Measurements of plutonium were made with a neutron multiplicity counter and a high-resolution gamma-ray spectrometer. This paper focuses on the hardware and software information barrier elements associated with gamma-ray spectrometers intended for use in cooperative monitoring regimes, including those of interest to the Trilateral Initiative.

1. Introduction

We will illustrate our application of information barrier principles to gamma-ray spectrometric measurements with a prototype instrument developed to demonstrate the Pu-600 method. The principal purpose of this method is to make nonsensitive determinations of the presence of "weapons-quality" plutonium in sealed storage containers. In the next section we will quickly outline the physics basis of the method. Following that we provide a brief introduction to information barriers. We follow this with examples of techniques applicable to the certification and authentication of a gamma-ray measurement system.

2. Physics Basis of the Pu-600 Method

The Pu-600 method determines two attributes of plutonium: (1) the presence of plutonium and (2) the presence of "weapons-quality" plutonium. Pu-600 is typically used in conjunction with a neutron multiplicity counter that measures effective ^{240}Pu mass (the mass of ^{240}Pu that would give the same coincidence response as that obtained from all the even Pu isotopes in the item [3]). As in the Trilateral Initiative Demonstration, Pu-600 also provides the isotopics information needed to estimate the full plutonium mass.

The method examines a narrow energy region of the plutonium spectrum containing a complex multiplet of gamma-ray lines between 630 and –670 keV (Fig. 1). Pu-600 measures the relative amounts of the isotopes ^{240}Pu and ^{239}Pu. Because more than 99% of the mass of weapons-grade plutonium is ^{240}Pu and ^{239}Pu, a low value (< 0.1) of the ^{240}Pu/^{239}Pu ratio indicates the presence of "weapons-quality" plutonium. The Pu-600 analysis uses a variant of the MGA code [4] to determine peak areas in the 630-670 keV energy region (Fig. 2). The analysis algorithm exploits the fact that efficiency and attenuation variations are small

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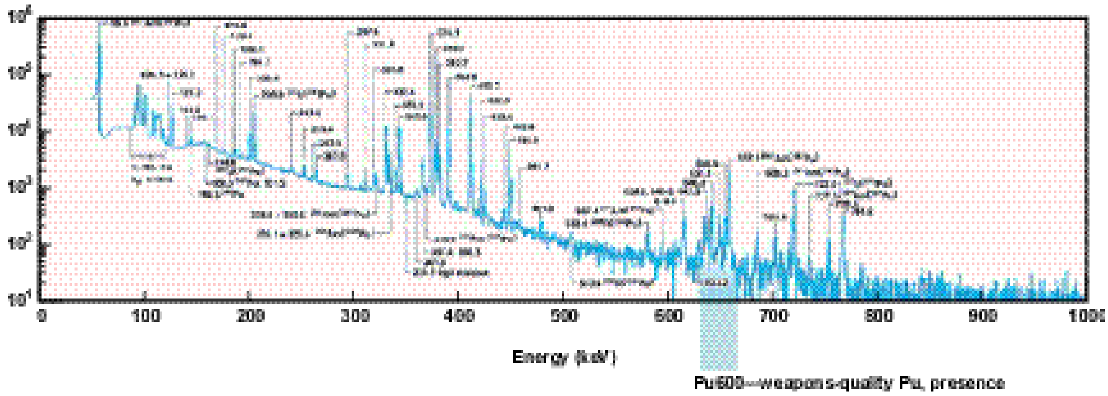

Figure 1. The first 1000 keV of the pulse-height spectrum of a nonsensitive, U.S. weapons-grade plutonium item. The narrow 630–670 keV region used for the Pu-600 analysis is illustrated.

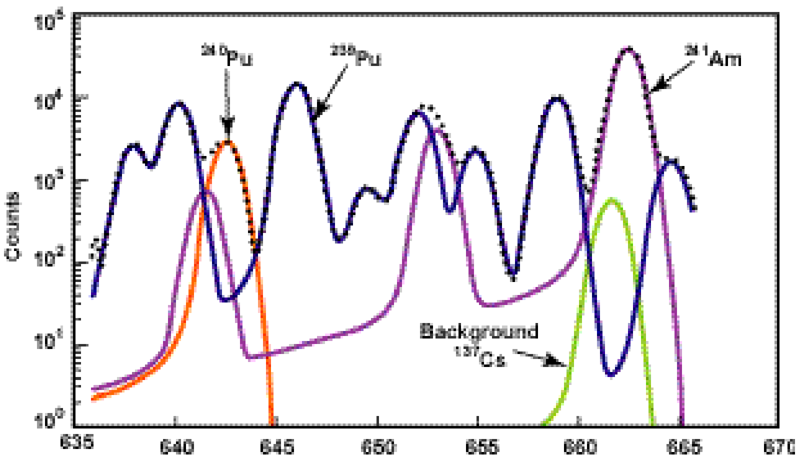

Figure 2. Resolution of the isotopic constituents by nonlinear regression analysis in the 630–670 keV region. Contributions from ^{239}Pu and ^{240}Pu are shown along with the ^{241}Am daughter of the impurity isotope ^{241}Pu. A small background peak from a ^{137}Cs source has been identified and resolved.

throughout this energy region. The ^{240}Pu/^{239}Pu ratio is proportional to the areas of the ^{240}Pu peak at 642.5 keV and the ^{239}Pu peak at 646.0 keV. The value of the ^{240}Pu/^{239}Pu ratio is passed, within the information barrier, to a computer called the Computational Block to be combined with the value of ^{240}Pu effective, measured by the multiplicity counter, to determine the plutonium mass.

The presence of plutonium is indicated by the presence of the 645.0 and 658.9 keV ^{239}Pu peaks at an intensity that exceeds five standard deviations above the continuum. The physics basis of the Pu-600 method has been discussed in greater detail in earlier papers [5,6].

3. Information Barriers

Radiation measurements are by nature intrusive. Radiation measurement information obtained from sensitive items will contain sensitive information. The system must include an *information barrier* in order to give the host party assurance that its sensitive information will not be revealed and that only the necessary result will be disclosed to the monitor. Information barriers [7,8] have become essential elements in systems designed for second-party monitoring of host items with sensitive characteristics. An information barrier is a combination of hardware, software, and procedures that protects *all* sensitive information but provides a small set of nonsensitive results that are required by the monitoring party and can be accepted with high confidence as genuine. The results for the attributes being measured are presented as binary (pass/fail) indicators such as red and green lights. The pass/fail determination is made by comparing (within the information barrier) the actual value of the attribute being measured with a nonsensitive threshold value agreed upon by the host and monitoring parties. Because the information barrier conceals all data except for a small set of essential, nonsensitive results, this complicates gaining assurance that the instrument is operating correctly and is giving genuine results.

The U.S. considers certification (protection of sensitive information) and authentication (assurance of the integrity of measured results) to be complementary concepts and thus certification and authentication are the focus of this paper—see subsections below. A third concept, system reliability assurance, is also essential for systems expected to see many years of service (Fig. 3). This latter concept is outside the scope of this paper.

The Pu-600 method, when it was applied to the Trilateral Initiative Demonstration of 1999, was modified to work within an information barrier. Since then information barrier elements have become integral to the method. Since 1999 we have refined the hardware used in the Trilateral Initiative Demonstration but the architecture of the gamma-ray system is unaltered. We will illustrate the Pu-600 information barrier elements with current system hardware.

4. Information barrier elements for protection of sensitive information

4.1. Only the data required are collected

One of the best ways to ensure that sensitive information is protected is not to collect it at all. What is not measured cannot be revealed. For this reason, the Pu-600 method collects data only in the narrow energy region illustrated in Fig. 1. Plutonium items have many plutonium isotopes and the detailed nature of the isotopics can be sensitive. Not only does the 630–670 keV region contain only a small fraction of the spectral data; it contains photopeaks from only the two plutonium isotopes of interest, ^{239}Pu and ^{240}Pu.

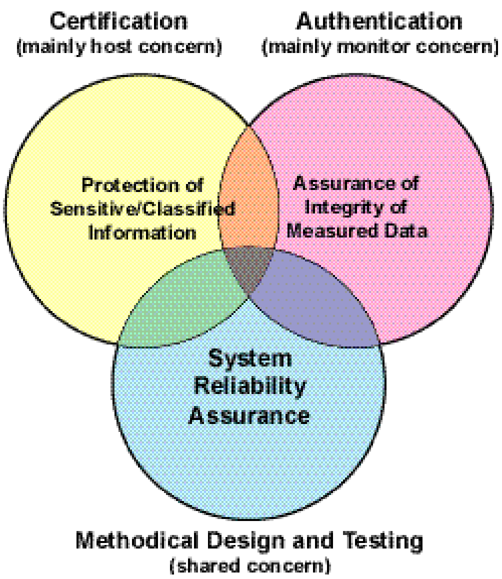

Figure 3. The current U.S. position considers authentication and certification to be complementary concepts.

4.2. Measurement technique should be independent of measurement environment

Spurious radiation sources in the measurement environment can adversely affect measurement results and may even mask them entirely. This problem can be overcome easily with massive shielding. For the Pu-600 gamma-ray detectors we use an annular shield around the cryostat that is 2 cm thick and made of machinable tungsten. We also place a machinable tungsten iris on the face of the detector so that the item being measured largely occupies the field of view.

4.3. Measurement technique should be independent of item geometry

The measurement method should also be independent of the geometry of the item being measured. If the source-to-detector distance and the data acquisition time have to be adjusted to accommodate varying gamma-ray output rates from varying item geometries, these very settings may reveal sensitive information about the items. Another reason for choosing the 600–keV range for the Pu-600 method is that gamma rays in the 600 keV region are quite penetrating—allowing us to measure a wide variety of items in a fixed geometry for a fixed measurement period.

Because high gamma-ray input rates alter photopeak shape, reducing the precision of photopeak analysis, we keep the Pu-600 system dead time under 15%. If the items and containers are all uniform, this is easily accomplished by selecting an optimum aperture for a fixed tungsten iris. If, instead, the items in the storage container vary considerably in geometry and fixturing, the gamma-ray output can vary over a wide dynamic range, making a fixed aperture iris ineffective. To address this eventuality, we developed an adjustable tungsten iris that performs autonomously; adjusting the aperture opening based on the gamma-ray-input rate observed by its associated count rate circuitry. The inset in Fig. 4 shows the front view of the iris on a test stand. To the right-hand side of the larger portion of Fig. 4**,** the iris can be seen from the side when it is mounted on the front of a Pu-600 detector. The massive tungsten shield is directly to the left of the iris and the stepper motor that actuates it is above the shield. The iris circuitry is located at the upper left-hand side of the detector enclosure. Because the enclosure is opaque, it conceals the size of the opening of the autonomous iris—an indicator of gamma-ray-input rate. Should power be removed from the system, a spring restores the aperture to its starting position.

4.4. The detector is isolated from RF leakage or interference

The enclosure shown in Fig. 4 acts as a radio-frequency shield to eliminate RF emanations from the detector that might contain sensitive information, such as the count rate. The enclosure also shields the detector and aperture electronics from external RF interference. The single-board computer (described below) that controls the instrument and analyzes the data is housed in a separate RF-shielded enclosure and connected to the detector enclosure with a shielded cable bundle.

4.5. Detector operation is automatic

The possibility of human error with the operation of the system is minimized by fully automating its operation. The simplest possible operator interface was devised, three push buttons, one for each of the three types of measurements that occur: energy calibration, background, and item assay.

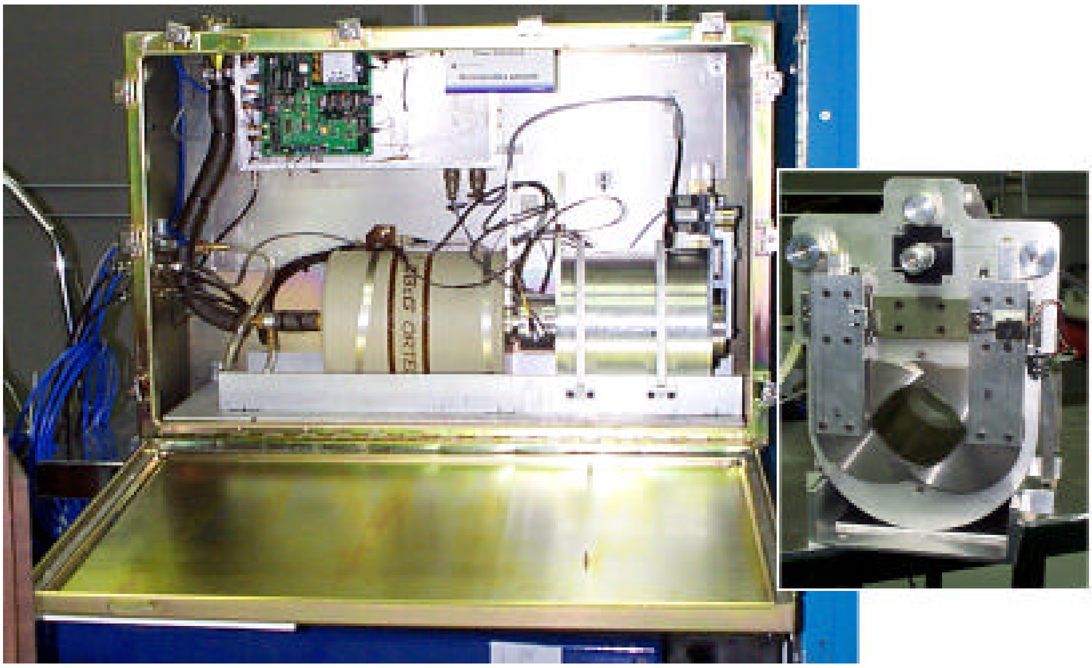

Figure 4. A Pu-600 detector system as currently configured. The inset shows a front view of the autonomous iris on a test stand.

4.6. Sensitive information resides only in volatile computer memory

When not in use, the measurement system should not retain any residual measurement information. For this reason read/write memory in the system should be volatile. In the Pu-600 system the battery manufacturer's memory backup in the data acquisition subsystem is disabled. The system control, and analysis software and the disk operating system reside in PROM. While we currently use the MSDOS operating system, we expect that any system that can be make certified or authenticated will use an open-source disk operating system—if it uses an operating system at all. Volatile RAM in the form of a "RAM disk" takes the place of mechanical rotating storage. When power is removed from the system all measurement information is lost. In the event of an inadvertent breach of the information barrier, an interlock removes power from the system.

5. Information barrier elements for ensuring the integrity of measured results

To assure the monitoring party of the integrity of measured results; we take a threefold approach. The first is to make the system as simple and as easily inspectable as possible, the second is to provide open and secure modes of system operation, and the third is to prepare nonsensitive reference sources with well-characterized attributes to test the system.

5.1. Inspectability (simplicity) is necessary for the monitors

To aid the monitors, an open layout of system components greatly enhances inspectability. The use of commercial equipment, if it can be certified, has some virtue in the area of trust. Anonymous purchase of commercial hardware/software can sometimes resolve trust issues. Still, U. S. preference seems to be moving away from commercial products because they tend to be more complex. For the Pu-600 system, we currently use a commercial, gamma-ray data-acquisition system. Because the control and analysis computer will contain both sensitive measurement data and the sensitive detailed results of the analysis, this component is of major concern. We desire to use a computer that provides only the functionality required for the measurement task. The typical commercial office or laptop computer provides far more functionality than we require. To date our approach has been to rely on the simplest single-board computers that provide adequate computing power. For the Pu-600 system we are currently using commercial, single-board computers based on the industry-standard PC104 bus. These computers have a minimal number of components, which simplifies inspection. We are also currently using one of the simplest industry-standard disk operating systems, MSDOS, and are investigating using an open-source operating system. We are also investigating means to further simplify the data acquisition system, the computer, and to completely avoid the use of any operating system [9].

Custom software for the control and analysis of data must be nonsensitive, open, and shared between the host and monitoring parties.

5.2. Open and secure modes of system operation

Two modes of system operation are necessary. Secure mode is the default mode of the system for measurement of sensitive items and only provides pass/fail indications for the attribute measurements. Open mode is necessary for system testing and for developing system confidence. Open mode provides the monitor with the ability to see detailed results of nonsensitive measurements, such as: background, energy calibration, and test runs with nonsensitive reference sources. Test runs with the same reference sources can then be made in secure mode to confirm the proper pass/fail operation.

5.3. Nonsensitive reference sources provide known values of the attributes of interest

Nonsensitive reference sources with well-characterized and sharable attribute values are needed that provide both pass and fail indications for all of the measured attributes. These allow for testing the operation of the system for proper response when it is in normal operation. The preparation of plutonium references sources is an expensive and time-consuming task. As a result, we have relied on nonsensitive items on hand as surrogates for true reference standards. Both decisions about what the specific characteristics reference standards should have and how to go forward with the preparation of these sources are determined by discussions between the host and monitoring parties.

6. Conclusion

The construction of prototype gamma-ray plutonium attribute measurement systems with information barriers has been very useful in dealing with practical problems of system integration and automation and also in revealing how improvements can be made. This paper has illustrated some of the practical approaches that we have taken in actually executing an information barrier design. The design elements discussed in this paper were implemented from within the framework of a conceptual information barrier architecture. The importance of a well-thought-out architecture cannot be overestimated.

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